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Assessment of Green Sea Urchin (*Strongylocentrotus droebachiensis*) Stocks in British Columbia, 2001

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ABSTRACT

This paper (i) provides an analysis of the green sea urchin fishery in British Columbia by updating information from the fisheries in 1998, 1999, and 2000 fishing seasons; (ii) provides suggestions for limit and target reference points for the 2001-2002 and 2002-2003 fishing seasons; and (iii) presents results from fishery-independent surveys of green sea urchins. Reference points were determined using biomass dynamic models applied to the core stocks in the South Coast – inside waters northern region (Queen Charlotte Strait; Pacific Fisheries Management Areas 11-13) and the South Coast – inside waters southern region (Gulf Islands; PFMA 17-20,28). Two methods were used to determine the parameters of these models: a linear approximation to the dynamic Schaefer model, and a time series fitting method. For both core stocks, both models produced similar (i.e. overlapping 95% confidence intervals) estimates of the maximum sustainable yields (MSY). The time series fitting method produced a lower MSY with narrower confidence intervals for the smaller stock (Gulf Islands region), and it is recommended as the more conservative method for calculating reference points. The calculated MSYs are recommended as limit reference points, with target reference points suggested in the range of 0.25 to 0.50 of MSY. The resulting target reference range for both core regions in the South Coast is therefore 96.3 to 192.5 t. Fishery-independent surveys have been conducted annually since 1995 at index sites in Area 12 (Queen Charlotte Strait) and indicate that the biomass of legal and sub-legal sized green urchins in this area in 1999 and 2000 were among the highest observed. Fishery-independent surveys in the Gulf Islands region have been conducted for two years. They show inconclusive trends in legal-sized biomass between the two key locations, but all locations appeared to have strong sub-legal sized biomass.

RÉSUMÉ

Ce document présente (i) une analyse de la pêche de l'oursin vert en Colombie-Britannique fondée sur la mise à jour des données pour les saisons de pêche 1998, 1999 et 2000, (ii) des suggestions de points de référence limites et cibles pour les saisons de pêche 2001-2002 et 2002-2003 et (iii) les résultats de relevés de l'oursin vert indépendants des pêches. On a déterminé les points de référence à l'aide de modèles dynamiques de la biomasse appliqués aux principaux stocks de la région côte sud – eaux intérieures du nord (détroit de la Reine-Charlotte; secteurs de gestion des pêches du Pacifique 11 à 13) et de la région côte sud – eaux intérieures du sud (îles Gulf; secteurs de gestion des pêches du Pacifique 17 à 20 et 28). On a déterminé les paramètres de ces modèles par deux méthodes : une approximation linéaire du modèle dynamique de Schaefer et une méthode d'ajustement de série chronologique. Pour les deux stocks principaux, les deux modèles ont donné des estimations semblables (c.-à-d. que leurs intervalles de confiance à 95 % se chevauchaient) des productions maximales équilibrées (PME). La méthode d'ajustement de série chronologique ayant donné une PME moindre et un intervalle de confiance plus restreint pour le plus petit stock (région des îles Gulf), on la recommande comme la méthode la plus conservatrice pour calculer les points de référence. On recommande d'établir les PME calculées comme points de référence limites, et d'établir les points de référence cibles entre 25 et 50 % du PME. Ainsi, la fourchette de référence cible pour les deux régions principales de la côte sud s'étend de 96,3 à 192,5 t. Selon les relevés indépendants des pêches effectués annuellement depuis 1995 à des sites indicateurs dans le secteur 12 (détroit de la Reine-Charlotte), les biomasses d'oursins verts de tailles légale et inférieure à la taille légale en 1999 et 2000 comptaient parmi les plus élevées jamais observées. Les relevés indépendants des pêches que l'on effectue dans la région des îles Gulf depuis deux ans ne montrent aucune tendance concluante de la biomasse des oursins de taille légale dans les deux principaux sites, mais il semble que la biomasse des oursins de taille inférieure à la taille légale soit élevée à tous les sites.

INTRODUCTION

Commercial harvesting for green sea urchins, *Strongylocentrotus droebachiensis*, in British Columbia began in 1987. The fishery was managed with few restrictions until 1991, when licence limitation was introduced to control record high effort and catches, followed by quota limitations in 1994 and an individual quota system with dockside validation in 1995. Previous stock assessments were conducted by Harbo and Hobbs (1996), Perry *et al.* (1998), and Perry and Waddell (1998, 1999). The Request for Working Paper prepared by the Fishery Manager for this fishery is included as Appendix I. The questions to be addressed by this Working Paper as outlined in the Request for Working paper are: Calculation of green sea urchin harvest quotas in all areas for which data are available; incorporation of relevant information from recent green urchin surveys; and presentation of biological data collected from commercial fishery sampling. Accordingly, the objectives of the current assessment are:

1) to provide an analysis of the green sea urchin fishery in British Columbia by updating the historical sales slip, harvest logbook, and port validation information with data from the October 1998 - March 1999, November 1999 - March 2000, and November 2000 to March 2001 fishing seasons;

2) to provide recommendations for harvest yields for the 2001-2002 and 2002-2003 fishing seasons; and

3) to present results from fishery-independent surveys of green sea urchins.

BIOLOGY AND FISHERY BACKGROUND

Biology

Green sea urchins occur in cool temperate waters in both the Pacific and Atlantic Oceans. They are circumpolar in the Pacific, occurring from northern Washington State through the Aleutian Islands and west to Hokkaido and Korea. They occur intertidally and to depths of >140 m, generally on rocky, gravel or shell substrates. Sexes are separate, with sizes at maturity of 25 mm in the Atlantic (Miller and Mann 1973) and from 35-45 mm in Alaska (Munk 1992). In B.C., the spawning period generally occurs during February and March. Larvae are pelagic for 9-10 weeks depending on temperature (Strathmann 1978), and in the Atlantic the upper temperature limit for larval development is 10°C. Green urchin growth rates vary considerably depending on food availability, with rates of 1 cm yr^{-1} recorded for the Strait of Georgia (Foreman and Lindstrom 1974) and slightly >1 cm yr^{-1} in Alaska (Munk 1992). On the Atlantic Coast, growth rates may be as low as 1-2 mm yr^{-1} under food-limited conditions (Himmelman 1986). It takes about 4 years (Munk 1992) for a green urchin to reach a test diameter of 55 mm (the minimum legal size in B.C.). Maximum test diameters can be >100 mm. Ageing of green sea urchins using rings on the coronal test plates

and the rotules (components of Aristotle's lantern) has indicated that animals from the Bay of Fundy on the Atlantic Coast may be up to 20-25 years old (Robinson and MacIntyre 1997). Green sea urchins appear to be more mobile than red sea urchins, and unpredictable (in space and time) aggregations are common. They may undertake deep-shallow migrations. Occasional large-scale mortalities of green sea urchins along parts of the Atlantic Coast of Nova Scotia between 1992 and 1995 have been linked to a marine amoeba, *Paramoeba invadens*, whose prevalence appears to be enhanced by water temperatures >10°C (Schiebling and Hennigar 1997). This amoeba has not been observed on the Pacific Coast of Canada to date.

Fisheries

Fisheries for green sea urchins occur on the Atlantic coast of Canada and in Maine, Alaska, and Washington states. In Alaska, green urchins are allowed to be harvested commercially only in the Central and Westward regions. The fishery in B.C. developed rapidly, with landings reaching a peak of 1042 t and a landed value of 4.4 million dollars in 1992, followed by a sharp decline. It is conducted by divers, and is principally a roe fishery whose product is landed and shipped live to the Japanese market. The fishery for green sea urchins is conducted during winter, with the highest market prices occurring around Christmas. It is managed with a 55 mm test diameter size limit, licence limitations and, beginning in 1995, with area quotas, individual quotas, and area closures. Management actions since the inception of the fishery are summarised in Table 1. Submission of sales slips and harvest logbooks are conditions of licence. In the assessments of Perry *et al.* (1998) and Perry and Waddell (1998, 1999), the data analyses were conducted on a "fishing season" basis, i.e. from the fall of one year to the spring of the following year. This lead to revision of the licence year so as to expire in spring (31 May). The fishery is conducted by SCUBA divers using small vessels due to the patchy distribution of the resource. In the early 1990's, the fishery expanded to remote locations with the addition of packer vessels (Harbo and Hobbs 1996). Fishers report that their fishing practices have changed as a result of quota restrictions and market demands for high quality roe, i.e. they now spend more time searching for high quality roe. However, some fishers on the South Coast indicate that despite the increased search time they continue to fish the same grounds with catches similar to previous years. The North Coast fishery suffered from poor roe yields and quality (Harbo and Hobbs 1996), and has generally been closed to commercial fishing since 1997.

Perry *et al.* (1998) and Perry and Waddell (1998, 1999) recommended separating green sea urchin populations on the B.C. coast into four broad "stocks", rather than assuming they represent a single contiguous population. This present assessment follows this recommendation of four stocks [B.C. North Coast (Pacific Fishery Management Areas 1-10); South Coast - inside waters northern component (PFMA 11-16); South Coast - inside waters southern component (PFMA 17-20, 28, 29) (Fig. 1); and the west coast of Vancouver Island]. We justify this on the basis of the expected duration of the planktonic larval stages (1-2 months at prevailing winter-spring temperatures of 6-10°C; e.g. Hart and Scheibling 1988), and the general circulation of B.C. inside waters. Thomson (1981) indicates the northern Strait of Georgia has a weak circulation (except for the strong tidal

currents near Seymour Narrows) with a possible counter-clockwise pattern; this should separate the two components of the South Coast - inside waters. Thomson (1994) cites the results of estimates of the winter flushing time for the Strait of Georgia as 3-6 months, sufficiently longer than the expected larval duration of green urchins. However, there may be greater exchange of larvae between the South Coast - inside waters southern component and the west coast of Vancouver Island.

METHODS

All analyses in this current assessment are presented on a "fishing season" basis, defined as 1 June of year i to 31 May of year i+1; in practice for the recent years of the fishery this reduces to 1 October of year i to 31 March of year i+1. A "fishing season" is denoted by the year fishing started, i.e. year i, so that the 1997 fishing season includes 1 October 1997 to 31 March 1998.

Basic information on landings (L) and landed values are derived from sales slip information as collected by the Catch and Effort Unit of the Biological Data and Analysis Division (DFO, Vancouver). Detailed information on catch, effort, depth and locations fished for all fishing seasons (1987-2000) are provided in the fishers' harvest logbooks. Perry and Waddell (1998, 1999) used the median annual catch per unit of effort (U_{mi})

(1) $$U_{Mi}=\text{median}_j\left(\frac{c_{ij}}{e_{ij}}\right).$$

with c_{ij} and e_{ij} representing the catch (c) and effort (e) for year i from harvest logbook records (j) with non-zero entries for effort, as a robust measure of CPUE; this practice is continued in the present assessment. The standard error of the median (se_{Mi}) was calculated as 1.2533*se_i (Sokal and Rohlf 1981, p. 139), with se_i the standard error of the annual mean catch per unit of effort as calculated from individual logbook records. Since landings in the harvest logbooks for the fishing seasons from 1988 to 1990 represent <90% of the saleslip landings (see Results - The fishery, below), total effort (E_{Ti}, in diver hours) in fishing season i (i = 1988, 1989, 1990) was estimated as saleslip landings (S_i) divided by the catch per unit of effort (U_{Mi}) from the harvest logbook database

(2) $$E_{Ti}=\frac{S_i}{U_{Mi}}.$$

Justification for the use of the median CPUE is provided by the analysis of Perry and Waddell (1998). Values of catch per unit of effort calculated from individual harvest logbook records showed many high outliers in every fishing season. Some of these outliers undoubtedly result from errors in the harvest logbooks, for example, when the same number of hours fished is entered for every dive over several days of fishing. To reduce the influence of these outliers, the median catch per unit of effort (U_{Mi}) was calculated. In every fishing season, the median U_{Mi} provided the lowest estimate of catch per unit of effort compared with other methods of estimating

CPUE (Perry and Waddell 1998). The time trends were similar amongst all the three estimates examined. The median U_{Mi} and its standard error were chosen as a robust estimator of catch per unit of effort.

Biomass Dynamic Model

Development of a biomass dynamic production model followed the approaches outlined in Schnute (1977), Polovina (1989) and Hilborn and Walters (1992). Schnute (1977) developed a linear approximation to the dynamic Schaefer production model as

(3) $$\ln\left(\frac{U_i}{U_{i-1}}\right) = r - q(E_{i-1} + E_i)/2 - \left(\frac{r}{qk}\right)(U_{i-1} + U_i)/2 \quad .$$

with U_i the catch per unit of effort for year i (here using U_{Mi}), E_i the effort for year i (using E_{Ti} for 1988-1990), r the intrinsic rate of population increase of biomass, q the catchability coefficient, and k the unexploited biomass. This equation can be represented as a regression of the form

(4) $$Y_i = \alpha + \beta X_i + \gamma Z_i + \varepsilon_i$$

with

$$Y_i = \ln(U_i/U_{i-1})$$
$$X_i = (E_{i-1} + E_i)/2$$
$$Z_i = (U_{i-1} + U_i)/2$$

and ε_i a lognormal error term. The parameters α, β, γ are then equal to r, $-q$, and $-r/(qk)$, respectively. Solutions to this regression equation were calculated using S-Plus.

Once r, q, and k are known, the traditional Schaefer model under equilibrium conditions with C_i the expected catch, is represented as

(5) $$C_i = qkE_i\,(1 - (q/r)E_i) \quad .$$

Hilborn and Walters (1992) provide the following summary of management parameters once the parameters of the Schaefer model have been determined:

Maximum surplus yield (MSY)	$rk/4$
Stock size for MSY	$k/2$
Rate of exploitation at MSY	$r/2$
Effort required to achieve MSY	$r/2q$

Since 1995-96 all fishing plans have restricted fishing in the South Coast to the core fishing areas (PFMA 11,12,13; 17-20, 28). In the current assessment, the biomass dynamic production model was calculated using data for all years but only from these core fishing areas. Historically these core areas have contributed >90% to the coastwide landings of green sea urchins in B.C.

A time series version of the biomass dynamic model has been developed (Pella and Tomlinson 1969), and has been recommended by Hilborn and Walters (1992) as providing a better fit to data than other methods. Hilborn and Walters (1992) also recommend evaluation of different formulations of biomass dynamic models as a check on the performance (and assumptions) of these models. The basic equations for fitting the time series version of the surplus production model are:

(5) $$\hat{B}_{i+1} = \hat{B}_i + r\hat{B}_i(1 - \frac{\hat{B}_i}{k}) - C_i$$

(6) $$\hat{Um}_i = q\hat{B}_i$$

with C_i the observed catch, $\hat{Um}_i$ and $\hat{B}_i$ the predicted median catch per unit effort and biomass at year i, and q, r, and k are the parameters of the surplus production model, as described above. We also assume that the error for the observed median CPUE (Um_i) is multiplicative and log-normal with a constant coefficient of variation, i.e.,

(7) $$Um_i = \hat{Um}_i e^{\varepsilon} = q\hat{B}_i e^{\varepsilon}, \qquad \varepsilon \sim N(0;\sigma^2)$$

and that the biomass at the first year of the fishery is equal to the unexploited biomass. The estimates of the model parameters (q, r, k), biomass (B_i), and CPUE ($\hat{Um}_i$) are obtained by adjusting various combinations of q, r, k until the following likelihood function is maximised

(8) $$L = \prod \frac{1}{\sqrt{2\pi}\hat{\sigma}} \exp\left(\frac{-\left(\ln(Um_i) - \ln(\hat{Um}_i)\right)^2}{2\hat{\sigma}^2} \right)$$

where $\hat{\sigma}$ is the estimated standard deviation of the errors for the observed CPUE data

$\hat{\sigma}^2 = \sum \frac{(\ln(Um_i) - \ln(\hat{Um}_i))^2}{n}$ (n is the number of years for which CPUE data are available). Parameter values causing the population to go extinct before 1998 were not considered.

After obtaining the model parameters, 1000 sets of simulation data were generated using the Monte Carlo simulation technique. CPUE was reproduced for each set of the simulations according to a probability distribution (log-normal), the standard deviation of which was

estimated based on the original data (see Equation 8). Each set of simulated data was used to produce estimates of the model parameters. Thus, there were 1000 estimates of the model parameters, which provided a probability distribution for each parameter and for MSY.

Biological Subsampling of Landings

Subsampling the landings of green sea urchins was begun in 1996/97 in order to determine the sizes of animals landed and their variation among fishing areas. Dockside validators measured the test diameters of 25 green urchins from every landing. The harvest date and location were also recorded for each measurement.

Fishery-independent Surveys

Scientific surveys have been conducted to obtain biological and population information on green sea urchins in B.C. independent of the commercial fishery. These are small localised surveys designed to develop working relationships with industry and native fishery interests and to provide biological information from a part of the core fishing areas. In the Queen Charlotte Strait region, surveys have been conducted annually (or more frequently) since 1995. Waddell *et al.* (1997) provide a detailed report of the methods and of the first set of surveys (October 1995 and March 1996); reports of the other surveys are in preparation.

The locations of these surveys were in PFMA 12, at the intersection of subareas 5,6, and 18 in eastern Queen Charlotte Strait. Specific locations are the Stephenson Islets (50°34.5′ N, 126°49.5′ W), Stubbs Island, and the NW sector of the Plumper Group (Fig. 2). Stephenson Islets was identified by the fishing industry as a key, first-choice location for harvesting of green urchins. Fishery-independent surveys have been conducted less regularly in the Gulf Islands region, starting in 1997 in Active Pass but expanding to six additional locations in 1999 and 2000 (Fig. 3). In the Gulf Islands region, East Point on Saturna Island was considered to be the major fishing ground for green urchins. On each survey, the transect-quadrat technique was used, with quadrats (1 m^2) sampled along the transects by divers, working from deep to shallow. Green urchins were counted and test diameters measured on all surveys; subsamples were collected for measurements of weight and gonad condition. The mean densities of legal (≥55 mm test diameter) and sub-legal (<55 mm) green urchins were calculated for each study site using the procedures of Jamieson and Schwarz (1998)

(6)
$$\overline{D}=\frac{\sum_{i=1}^{n} N_i}{\sum_{i=1}^{n} L_i}$$

with standard error

(7) $$SE(\bar{D}) = \sqrt{\frac{1}{\bar{L}^2}\frac{1}{n}\frac{\sum (N_i - L_i(\bar{D}))^2}{n-1}}$$

in which n = the number of transects sampled in a study site, N_i = the total number of green urchins found in transect i, $i = 1,2,...n$, L_i = the total number of quadrats in transect i, and the average area of the transects is represented as

(8) $$\bar{L} = \frac{1}{n}\sum_{i=1}^{n} L_i$$

On average, there have been 10 transects sampled in the Stephenson Islets area, 3-4 around Stubbs Island, and 4-6 transects in the Plumper Group. Only 2-4 transects were generally sampled at each Gulf Islands location due to time and tide constraints. For repeat surveys, the same locations were sampled on each survey, but not the exact same transects as the divers' path underwater varied somewhat each time. The total number of urchins in each location was calculated by multiplying the density (D) by the area of the location, with this latter being defined by fishing logbook records (and calculated from chart datum to 10 m below chart datum using ArcView software). This density was converted to a biomass of legal and sub-legal sized urchins using test diameter – weight relationships determined from laboratory analyses of subsamples of urchins collected on each survey.

To cross-check the abundance estimates of the fishery-independent surveys in the Gulf Islands region, a Leslie depletion analysis was conducted using fishery-dependent data. This model is basically a linear regression of the form:

(9) $$y = qP_1 - qK_{t-1}$$

in which y is an abundance index (e.g. CPUE), q is the catchability coefficient, P_1 is the initial population prior to fishing, and K_{t-1} is the cumulative catch taken prior to time t (Hilborn and Walters, 1992, p. 393). In essence, the procedure draws a line through a plot of the abundance index versus the cumulative catch, with the point where this line crosses the x-axis representing the initial biomass. This version of the model assumes a closed population with no immigration, emigration, or natural mortality over the time period of the fishery (here from November to January).

Exploratory Fishing Protocol

An exploratory fishing protocol was developed in collaboration with the fishing industry to begin to provide information on green sea urchin aggregations and abundances in areas outside of the normal core fishing locations. Briefly, exploratory fishing was to be conducted by licensed industry vessels, which were allowed to sell their catch in the normal manner. For the South Coast, the catches were considered to be additional to the established quota since the protocol was not

available for areas open to fishing in the 1995-1996 fishing season. Each vessel was required to have a DFO authorised observer on-board at all times while fishing, to make detailed observations of the fishery and to ensure that the exploratory protocol was followed. This protocol required prior identification by the fisher of the proposed fishing "sites", defined to have an area of 1 nmi^2. For any site, the maximum time for divers to be in the water was 16 diver hrs. Once this limit was reached, fishing in the current site was to cease. The intent of this regulation was to broadly limit effort on any particular aggregation of urchins, while still allowing for information on catch per unit of effort. No proposals were submitted to conduct exploratory fishing in 1998-2000.

RESULTS

The Fishery

The history of this fishery has been one of boom, bust, and recovery. Perry *et al.* (2002) identify three stages (Fig. 4; Table 2): a developing period (1986-1990), with increasing effort, landings, and value but declining CPUE; a crisis period (1991-1993) with peak effort and landings which then declined sharply, and a minimum in CPUE; and a rebuilding-to-sustainable period (1994-present) characterised by active management measures, stable effort and landings, and increasing CPUE. Landings since the 1994 fishing season have been limited by quotas. Landings by Pacific Fishery Management Area by fishing season indicate the principal fishing areas in Fishing Season 2000 were PFMA 12, 13, 18, and 19 (Table 3a). Landings by statistical area by month for fishing seasons 1998, 1999, and 2000 (Table 4) indicate harvests occurred mostly in December and January. Historical landings on the North Coast are presented in Table 3b; only one minor commercial fishing event has occurred in this region since 1995. Comparison of landings reported from sales slips versus harvest logbooks (Table 5) indicates that the logbooks recorded greater than 96% of the sales slip landings since 1991, and that sales slips have (substantially) underestimated landings since 1995. Logbook records since 1995 have been verified against the dockside validation records from the individual quota system. Logbooks underestimated landings from 1988 to 1990, therefore, the total effort for these years (as input into the biomass dynamic model) has been adjusted using equation 2.

The median catch per unit of effort separated by major fishing region shows declining trends with fishing season until 1992 in the South Coast - inside waters southern region (PFMA 17-20, 28) and 1993 in the South Coast - inside waters northern region (PFMA 11, 12, 13), and an increase since 1994 (Fig. 5). This increase has been sustained in both regions into the most recent fishing seasons. The standard errors about the medians are small.

Test diameters from commercial landings sampled in fishing seasons 1999 and 2000 were well above the minimum legal size of 55 mm, consistent with results from previous years (Fig. 6). Median diameters in PFMA 13 tended to be smaller than those in Areas 11 and 12, and in the southern Strait of Georgia, median diameters tended to be larger in Area 19.

Biomass Dynamic Model

The pattern of median CPUE versus effort over time (Fig. 7) for the green sea urchin fishery in both core regions had sufficient contrasts to enable the use of surplus production modelling to define biological reference points for management actions. The predicted catches from the Schnute version of the surplus production model are shown in Fig. 8. The maximum surplus yield (MSY ± 95% confidence interval) for the Queen Charlotte Strait region (PFMA 11-13) was 288 ± 20 t, with a model R^2 of 0.71 and a P-value of 0.002. The MSY calculated for the Gulf Islands region (PFMA 17-20,28) was 85 ± 43 t; the wider 95% confidence interval is consistent with the poorer fit of the regression model ($R^2 = 0.34$; $P = 0.13$; Table 6).

The time series fitting method produced maximum likelihood estimates of MSY of 308 t with two standard deviations (approximating the 95% confidence interval) of 38 t for the Queen Charlotte Strait region, and an estimate of 77 ± 9 t for the Gulf Islands region (Fig. 9). Changing the assumptions of the model to additive errors and/or setting the initial biomass to the initial CPUE/q changed the values of MSY very little (range of maximum likelihood MSY for Queen Charlotte Strait was 295 to 324 t, and for the Gulf Islands it was 77 to 79 t), indicating this model was robust to initial specifications. Both approaches (Schnute's, and the time series fitting method) to calculating the surplus production model for green sea urchins in these regions produced comparable results, since their 95% confidence intervals about MSY overlapped. The time series fitting procedure produced a lower MSY and smaller confidence interval for the southern region (the region with the smaller, and therefore potentially more vulnerable to overfishing, biomass), therefore this method should be selected as generating a more conservative result.

Fishery-independent Surveys

Six surveys have been conducted during the fall (just prior to the opening of the fishery) since October/November 1995 in the Stephenson Islets area of eastern Queen Charlotte Strait (PFMA 12). The mean densities calculated from these surveys indicate minima in biomass of both legal and sub-legal sized green urchins during fall 1997, and then an increase such that the highest biomass of legal-sized urchins in Stephenson Islets was observed during the November 1999 survey (Fig. 10). Sub-legal biomass has continued to increase. Mean legal biomass at Stubbs Island has also increased since 1998, and has increased at Plumper Island since 1999. At all locations, the biomass of sub-legal sized green urchins in 2000 was the highest observed.

Biomass estimates from fishery-independent surveys in the Gulf Islands (Fig. 3) ranged from 2.4 to 129.6 t for legal-sized urchins, and from 0.3 to 498.4 t for sub-legal sized urchins (Table 7). Highest biomasses were estimated from East Point and Collinson Point, both of which also had very high biomasses of sub-legal sized animals. These were also the two locations that were sampled for two consecutive years, and they indicated opposite trends in abundance. The abundance of legal-sized

urchins at Collinson Point more than doubled between fall 1999 and 2000, whereas the abundance of legal-sized animals at East Point declined by 41%. Note, however, that at both locations the biomass of sub-legal urchins increased by 23-38%. These changes represent actual increases in the abundance of sub-legal urchins, as well as changes in biomass (growth).

Sufficient data were available from East Point during the 1999 fishing season to estimate the pre-fishery biomass of legal-sized animals using the Leslie depletion method. The regression of individual catch per unit of effort versus the cumulative catch (Fig. 11) provides a biomass estimate for this location of 90.5 t. This compares favourably with the legal-sized biomass estimated at East Point of 129.6 t from the fall 1999 fishery-independent survey. One might expect the survey estimate to be higher than the fishery-dependent depletion estimate as the survey should count every urchin whereas the fishery is likely to leave some animals on the bottom.

These abundance estimates from the fishery-dependent and fishery-independent data should be treated cautiously. There were relatively few quadrats in the surveys, mostly due to difficulties with the strong tides (in particular at East Point). In addition, the estimates of the bed areas are based on fishery data, which varies annually and may not represent the true bed areas. In the depletion estimates, the regression fit to the data was poor, and was not statistically significant ($P = 0.48$). A comment must also be made about Sooke Bluffs. Two surveys were conducted in this location, in January of 2000 and 2001. Relatively few urchins were observed in January 2000, and none were observed in January 2001. However, just a few days after the January 2001 survey, the fishery landed 2.3 t of urchins from this location over a two day period. These urchins had apparently been caught unusually deep along the edge of the shelf. Fishermen report this location is unusual and difficult to fish because the urchins seem to move unpredictably in and out of the fishable depth range.

Yield Recommendations

MSY estimates from the time series fitting method are assigned to each management area on the basis of the proportion that area contributed to aggregate landings (on a fishing season basis) from 1988 to 2000 (Table 3a). Traditionally, MSY values have been considered as targets which management actions should try to achieve. However, many of the assumptions of surplus production models, such as no change in gear efficiency, constant catchability (in time, space, and across ages), a linear relationship between CPUE and effort, and equal availability of the fish to the fishery (Perry et al., 1999) are not likely to be true for a developing fishery such as for green sea urchins, particularly regarding the discovery of new patches of urchins as the fishery expanded. Therefore, the MSY values calculated in this assessment were defined as <u>limit</u> reference points, which management actions should ensure are not exceeded. The <u>target</u> reference points, to which management actions should aim, should be set sufficiently far from the limit reference point to ensure the limit point is not exceeded. Gabriel and Mace (1999) recommend setting quotas at 0.6 to 0.9 times MSY, whereas Garcia et al. (1989) recommend maximum target yields of 0.5 to 0.67 of MSY. Considering the history of this fishery (development then crisis),

the relatively sedentary and patchy distribution (therefore susceptible to "mining" of patches as the fishery developed), and the lack of an overall biomass estimate, target reference points for total allowable catches are recommended in the range of 0.25 to 0.5 of MSY for each of the core fishing regions. The specific recommendations for each PFMA, based on the results from the time series fitting method, are indicated in Table 8. The range in recommended total yield for PFMA 11, 12, 13, 17-20, 28 combined is 96.3 - 192.5 t. If one assumes that the biomass at MSY can be estimated as $k/2$ from the surplus production models (Schnute, 1977, Hilborn and Walters, 1992), then harvest removals of this magnitude would represent exploitation rates of 5-17% of this biomass, depending on the particular stock and reduction from MSY.

DISCUSSION

In this assessment we have introduced a second method of calculating the biomass dynamic model, i.e. the time series fitting method. Both the time series and Schnute methods of evaluating the parameters of this model produced similar (within their 95% confidence intervals) results, which provides some confidence that the biomass dynamic model is reasonably robust to initial specifications, at least within its assumptions. Since these assumptions, such as no change in capture efficiency over the time series, constant catchability, and a linear relationship between CPUE and effort (Perry *et al.*, 1999) are important for this fishery, the MSY values calculated from the models are recommended as limit reference points for management actions. Target reference points are suggested within the range of 0.25 to 0.50 of MSY, providing exploitation rates of 5-17% depending on the stock and the assumptions used to estimate the fishable biomass. Analyses presently underway of fishery-independent survey data suggest that, at least for a "hot spot" such as Stephenson Islets, exploitation rates on the order of 20% have had no negative impact on this stock.

The green sea urchin stocks that are surveyed in the Queen Charlotte Strait region of Area 12 (Stephenson Islets, Stubbs Island, and Plumper Island) appear to remain strong, with high biomass of both legal-sized and sub-legal sized urchins at all three locations in the most recent survey (November 2000). In the Gulf Islands region, there are at most two consecutive years of survey data, during which legal-sized biomass went up at two locations and down at a third. Sub-legal biomass, however, appears strong at all locations, and is substantially greater than the legal-sized biomass at the two principal fishing locations (Table 7). We also note comments from fishermen provided to the port validators that "Harvests from Areas 18 and 19 were good [in fishing season 2000]. Harvest rates seemed good and fishermen reported abundance of greens throughout the area compared to last season – good recruitment" (D&D Pacific Fisheries. 2001. 2000/2001 Green Sea Urchin Fishery. Pacific Region. Confidential Report prepared for DFO, p. 13). We recommend that a location in a principal fishing area in the Gulf Islands that could be monitored on an annual basis would be valuable to observe trends in the green urchin stocks in this region, as has been done with Stephenson Islets in Area 12.

Additional studies of green sea urchin biology, in particular as it relates to potential growth rates and age validation (rather than the use of size frequency analyses to infer age classes) would help to increase knowledge of this species in B.C. waters and provide confidence to assessing future changes in these populations.

SUMMARY OF RECOMMENDATIONS

1) Yield Options

Yield options for the 2001-2002 and 2002-2003 fishing seasons by management area should consider the estimated MSY's as limit reference points. Target yield options are suggested in the range of 0.25 to 0.50 of MSY (96.3 to 192.5 t for all areas combined).

2) Fishery-independent surveys and biological information

Fishery-independent surveys should continue in Area 12, and a site should be selected to continue annual surveys in the Gulf Islands (Area 18 or 19). Experimental studies on growth rates and age determination should continue.

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Table 1. Summary of management actions in the green sea urchin fishery, 1987 to 2000/2001.

Year	Management Actions
1987	Scientific permits were issued, July 22 to December 31, to fishing vessels for harvest by diving. Logbooks were issued with permits to collect data on stock abundance and distribution. Permits were limited to the inside waters of Vancouver Island, Areas 12 to 19, 28 and 29. Some minor area closures for parks or study areas were in effect as for most dive fisheries. A precautionary minimum size limit of 40 mm was set as a condition of the permit. Sales slip data did not have a separate species code, so green and red sea urchin landings are mixed. As a result, landings have been estimated from logbook returns and hails from processors. Effort was restricted by limiting the season to the months of traditional peak market demand for sea urchins, Oct.-Dec. and Jan.-Feb. Nineteen vessels reported landings.
1988	Permits were issued for the period Jan. 16 to Feb. 28. Sales data for green sea urchins was recorded with a separate species code. A conservative closure was set, Jan. 16 to Feb. 28 in subareas 13-1 to 13-3 due to the intensive fishery in a small area. A Z category (Z-A) licence for green sea urchins was introduced for the fall fishery which opened Oct. 1. The minimum size limit was increased to 55 mm test diameter and set as a condition of licence. The season was limited again, Jan. 1-Feb. 28 and Oct. 1-Dec. 31. Sixty-eight vessels reported landings.
1989	The Z-licence, minimum size limit and seasonal restrictions continued. A conservation closure was set for subareas 12-1 and 13-29 to 13-40, north of Campbell River, Jan. 31-Feb. 28/89 due to heavy fishing pressure and a high incidence of undersized urchins landed. One hundred thirteen vessels reported landings.
1990	The Z-licence, minimum size limit and seasonal restrictions continued. There were 91 vessels reporting landings. Licence limitation for 1991 was announced with the eligibility criteria of landings of 9,072 kg (20,000 lb.) over the two year period 1988 and 1989. At least 33 vessels were expected to qualify before appeals were held.
1991	Licence limitation – 47 vessels qualified and 47 vessels reported landings.
1992	A conservation closure was set in the Kelsey Bay area, subareas 12-1, 13-32, 13-33 and 13-35, Feb. 25-Feb. 28. These subareas did not reopen for fall fishing until Dec. 7.
1993	Licences increased to 49. Notification of fishing required. No suction devices. Additional permanently closed areas for parks and reserves, IFF. South Coast: Reduced fishing times; Inside waters: season Jan. 4 to Jan. 28, 7 days/wk; Feb. 1 to Feb. 25, 4 days/wk, Mon.-Thurs. Fall fishery Nov. 1 to Dec. 16, 4 days/wk, Mon.-Thurs.; Dec. 6 to Dec. 30, 7 days/wk. Kelsey Bay limited to 7 days, Jan. 4 to 10. W.C.V.I.: season reduced to Oct. 4 to 28, 1992, 7 days/wk. North Coast: 7 days/wk, season reduced to Jan. 1 to Feb. 28 and Oct. 1 to Dec. 31.
1994	South Coast: A ceiling catch of 990,000 lb (449 t) was set along with area quotas. Fishers requested to harvest 25% in Jan.-Feb. and the balance in Nov.-Dec. The days fishing were limited to four days/week (M-R) for some periods and others at 7 days/week. North Coast: No quota set; season reduced to periods Jan. 1 to Feb. 28 and Nov. 1 to Dec. 31. Consideration will be given for spring/summer fisheries depending on roe quality and landings.
1995/96	Fishing licences changed to expire on May 31, 1996. No fishing occurred prior to Nov. this year. South Coast: Pilot individual licence quota (IQ) system implemented with port validation. Area quotas also established, with total of 382,276 lb (173.4 t). Only Areas 12, 13, 17 to 20, and 28 open; other areas available under an exploratory protocol. Fishing season was Nov. 20, 1995 to May 31, 1996. North Coast: No individual quotas. Areas 3 and 4 only open from Nov. 20, 1995 to Jan. 31, 1996, with quota of 200,00 lb (90.72 t). Other areas open to fishing only under an exploratory protocol.
1996/97	Harvest logs and validation forms combined onto one sheet. Biosamples (sample test measurements) were collected by validators. South Coast: IQ system still in effect (quota divided between 49 licence holders), with port validation. Area quotas established, with a total of 359,435 lb (163.0 t). Only Areas 12, 13, 17 to 20 and 28 open; other areas available under an exploratory protocol. Fishing season was Nov. 12, 1996 to Jan. 31, 1997, with an extension to Feb. 15, 1997. North Coast: North Coast closed, except under an exploratory protocol.
1997/98	Two year Management Plan (October 15, 1997 to May 31, 1999). Second season of the extended pilot program (validation process). Biological sampling of commercial catch South Coast: Areas 11, 12, 13, 17 to 20 and 28 open from Nov. 10, 1997 to Mar. 15, 1998; other areas available under an exploratory protocol. Area quotas, with total of 366,079 lb (166.1 t) (IQ 7,471 lb). North Coast: North Coast closed, except under an exploratory protocol. Survey undertaken in Area 4.
1998/99	Third season of the extended pilot program (validation process). Biological sampling of commercial catch. South Coast: Areas 11, 12, 13, 17, 18, 19, 20, and 28 open from Nov. 10, 1998 to Mar. 15, 1999; other areas available under an exploratory protocol. Area quotas, with total of 366,079lb (individual quotas 7,471 lb). North Coast: Total quota of ~12,725 lb allotted to Area 4 from Feb. 12 to Mar. 15, 1999.

1999/2000	Validation program continued. Biological sampling of commercial catch. South Coast: Areas 11, 12, 13, 18, 19, and 20 open from Nov. 10, 1999 to Mar. 15, 2000; other areas available under an exploratory protocol. Note Areas 17 and 28 are closed due to conservation concerns. Area quotas, with total of 414,393 lb (individual quotas 8,457 lb). North Coast: Total quota of 13,000 lb allotted to Area 4. Season open from Jan. 21 to Mar. 15, 2000.
2000/2001	Validation program continued. Biological sampling of commercial catch. South Coast: Areas 11, 12, 13, 18, 19, and 20 open from Nov. 10, 2000 to Mar. 15, 2001; other areas available under an exploratory protocol. Conditional surveys for Areas 18 and 20 were performed which allowed those areas to stay open with the same quotas as the previous year. Area quotas, with total of 414,393 lb (individual quotas 8.457 lb). For the fishing seasons in 1999/2000 and 2000/2001, fishery managers set quotas at the 0.5*MSY level recommended in Perry and Waddell (1999) for PFMA 11-13, and at the 0.25*MSY level for PFMA 17-20,28, to reflect greater concern for the stocks in the Gulf Islands region. North Coast: Total quota of 13,000 lb allotted to Area 4. Season open from Nov. 10, 2000 to Mar. 15, 2001. First Nations had conservation concerns about the resource. Commercial fishers agreed not to fish the area this season.

Table 2. Green sea urchin landings (tonnes) and effort for British Columbia, by fishing season (Oct./Nov. to Mar.), 1986/1987 to 2000/2001, as reported on sales slips, harvest logbooks, and validation logs. Bold print is the most reliable value when a choice of sources of data is shown.

Season	Licence Type	Number of Licences Issued	Vessels with Landings	Fishing Days	Average Fishing Days/ Vessel	Total Landings (t)	Total Landed Value ($1000)[10]	Average Landed Value ($/t)	Mean Overall CPUE (t/vessel day)	Mean Overall CPUE (kg/ Diver hr)[6]	Total Diver Hours	Average Hr/Diver Day[6,8]	Total Number of Divers	Average Hr/Vessel Day[6]
1986/87[1]	Permit[5]					n/a	n/a	n/a						
1986/87[2]			2	4	2.0	2			0.50	175	14[7]	n/a	1[+]	3.38
1987/88[1]	Z					n/a	n/a	n/a						
1987/88[2]			29	290	10.0	207			0.71	171	1.216[7]	2.96	48[+]	4.57
1988/89[1]	Z		**77**			**480**	669	1.395						
1988/89[2]			63	688	10.9	378			0.55	156	2.418[7]	2.84	118[++]	4.67
1989/90[1]	Z		**115**			**642**	1.104	1.719						
1989/90[2]*			93	1.095	11.8	484			0.44	131	3.691[7]	2.47	169[++]	3.79
1990/91[1]	Z		**71**			**455**	981	2.155						
1990/91[2]*			51	923	18.1	353			0.38	107	3.310[7]	2.70	106[+]	4.25
1991/92[1]	Z		**49**			**783**	2.534	3.235						
1991/92[2]*			44	1.510	34.3	753			0.50	100	7.523[7]	2.88	152[+]	5.72
1992/93[1]	Z		**56**			**978**	4.530	4.632						
1992/93[2]*			53	1.987	37.5	954			0.48	81	11.835[7]	3.10	199[++]	6.77
1993/94[1]	Z		**53**			**577**	3.145	5.453						
1993/94[2]*			52	1.267	24.4	533			0.42	69	7.667[7]	2.94	183[++]	7.39
1994/95[1]	Z		**43**			**223**	**1.614**	7.251						
1994/95[2]			42	673	16.0	221	1.604		0.33	70	3.161[7]	2.73	101[++]	5.23
1995/96[1]*	Z	49	36[9]			135[9]	919[9]	6.805						
1995/96[2]			**39**	500	12.8	**157**	**1.071**		0.31	71	2.201[7]	2.84	85[++]	4.75
1995/96[3]			**39**	547	14.0	**157**	**1.071**		0.29					
1996/97[1]*	Z	49	31[9]			133[9]	838[9]	6.282						
1996/97[2]			**32**	458	14.3	**150**	**942**		0.33	65	2.300[7]	2.62	72[+]	5.03
1996/97[3]			**32**	467	14.6	**150**	**942**		0.32					
1997/98[1]*	Z	49	27			148[9]	931[9]	6.277						
1997/98[2]			**27**	423	15.7	**160**	**1.004**		0.38	82	1.958	2.57	59	4.63
1997/98[3]			**27**	n/a	n/a	**160**	**1.004**		n/a					
1998/99[1]*	Z	49	21[9]			107[9]	668[9]	6.214						
1998/99[4]			**26**	376	14.5	**156**	**968**		0.41	84	1.861[7]	2.71	60[+]	4.98
1999/00[1]*	Z	49	24[9]			141[9]	878[9]	6.228						
1999/00[4]			**27**	357	13.2	**187**	**1.162**		0.52	103	1.810	2.82	65	5.07
2000/01[1]*	Z	49	21[9]			86[9]	n/a	n/a						
2000/01[4]			**28**	314	11.2	**181**	n/a		0.58	107	1.701	3.05	56	5.42

See footnotes next page

Table 2. Continued (footnotes for above table).

* incomplete data (missing landing or effort data in the harvest logbooks).
[1] from sales slip data
[2] from harvest logbooks
[3] from validation logs
[4] from combined harvest/validation logbooks
[5] scientific permits were issued to 38 vessels for fall 1987 to spring 1988 fishery. 1987 landings and fishing days are from harvest logs as green sea urchins were not separated from reds on sales slips until mid-1998. Note a vessel can hold more than one licence.
[6] excludes records with missing fishing hours (effort)
[7] incomplete records of fishing hours (effort)
[8] excludes records with missing diver identification
[9] preliminary values likely lower than actual
[10] Landed values for sales slip data calculated as the summation of landed weight multiplied by the unit price for every landing. Landed values for harvest or validation log data calculated as the average landed value ($/t) from sales slip data, multiplied by total landings (t) from harvest or validation logbook data.
+ possibly one or two more (due to sales slips with no CFV #, or missing diver codes)
++ probably several more (due to missing diver codes)

Table 3a. Summary of green sea urchin landings (tonnes) by management area for the South Coast by fishing season (Oct. to Mar.), 1988/89 to 2000/01, as reported on sales slips (SS), harvest logs (HL) and validation logs (VL). ("-" = area closed; * = preliminary data). Totals were calculated using sales slips from 1988/89 to 1994/95 and harvest logs from 1995/96 to 2000/01.

PACIFIC FISHERY MANAGEMENT AREA

	East Coast Vancouver Island											West Coast Vancouver Island							
Season	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**28**	**29**	**20**	**21**	**23**	**24**	**25**	**26**	**27**	**Annual Landings**
SS 1988/89	2.8	93.0	171.8	17.0	7.4	0.3	15.4	53.8	74.5	15.0	9.8	1.5		2.5	9.5				474.3
SS 1989/90		327.9	129.8	5.6			36.1	87.6	23.8	1.8	0.5	2.1		0.4	1.8			12.6	630.0
SS 1990/91	0.9	105.4	153.4			0.1		121.9	51.1	4.0		15.7							452.5
SS 1991/92	1.0	388.4	203.5	3.1	1.3	4.1	1.1	42.6	50.5	4.3	18.6	61.4	0.3		0.4			2.0	782.6
HL 1991/92	0	353.7	206.1	1.4			0.1	23.1	66.3	0	25.4	76.1			0.1				752.4
SS 1992/93	43.4	645.4	189.6			1.9		18.9	36.2	1.7	2.6	36.2							975.9
HL 1992/93	70.8	631.4	154.1			1.3	0.5	26.0	38.6	1.7	2.8	26.7							954.0
SS 1993/94*	1.5	250.9	102.1	0.9	1.0		0.8	28.3	60.7	0.4	0.8	16.2	3.8		0.4	0.4			468.2
HL 1993/94	27.6	214.1	92.6			0.7	1.7	39.9	46.3	0.5	0	16.9							440.6
SS 1994/95*	2.3	93.8	56.5	1.1	0	0.3	0	15.5	16.4	0	0.1	9.4	-	0	0	0	0	0	195.4
HL 1994/95	6.9	92.6	53.5	0	0	0	0.2	15.1	16.0	0	-	10.8	-	0	0	0	0	0	195.1
SS 1995/96*	-	46.3	49.8	-	-	-	0.4	10.6	18.0	0		6.0	-	-	-	-	-	-	131.1
HL 1995/96	0.7	60.5	54.8	-	-	-	0.4	12.2	18.3	0	0.1	6.1	-	-	-	-	-	-	153.1
VL 1995/96	-	61.9	53.8	-	-	-	0.4	13.0	18.0	0		5.7	-	-	0.2	-	-	-	153.0
SS 1996/97*	1.8	70.3	21.7	-	-	1.5	0	23.3	7.8	0	-	7.1	-	-	-	-	-	-	133.4
HL 1996/97*	2.8	77.0	27.0	-	-	-	0	18.1	17.4	0	-(0.4)	7.1	-	-	-	-	-	-	149.8
VL 1996/97	2.8	76.9	27.2	-	-	-	0	18.5	17.4	0	-	7.1	-	-	-	-	-	-	149.9
HL 1997/98*	2.4	76.5	39.9	-	-	-	0.7	16.3	17.4	0	-	6.8	-	-	-	-	-	-	160.0
VL 1997/98	2.4	76.5	39.9	-	-	-	0.7	17.0	16.7	0	-	6.8	-	-	-	-	-	-	160.0
HL 1998/99	0.7	76.6	39.8	-	-	-	0.3	14.9	16.7	0	-	6.6	-	-	-	-	-	-	155.6
HL 1999/00	3.0	105.5	56.3	-	-	-	-	8.8	9.0	-	-	3.7	-	-	-	-	-	-	186.3
HL 2000/01	0	104.4	56.3	-	-	-	-	9.2	9.1	-	-	2.3	-	-	-	-	-	-	181.3
Total 1988/89 to 2000/01	61.5	2405.3	1280.8	27.7	9.7	6.7	54.8	448.1	401.1	27.2	32.1	175.1	4.1	2.9	12.1	0.4	0	14.6	4965.0
% of Total	1.2	48.4	25.8	0.6	0.2	0.1	1.1	9.0	8.1	0.5	0.6	3.5	0.1	0.1	0.2	0.0	0.0	0.3	

Table 3b. Summary of green sea urchin landings (tonnes) by management area for the North Coast by fishing season (Oct./Nov. to Mar.) 1988/89 to 1999/2000, as reported on sales slips (SS) and harvest logs (HL). The fishery was closed in the North Coast during the 1996/97 and 1997/98 fishing seasons. Totals were calculated using sales slips from 1988/89 to 1994/95 and harvest logbooks from 1995/96 to 2000/01.

	PACIFIC FISHERY MANAGEMENT AREA										
Season	**1**	**2E**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Annual Landings**
SS 1988/89		0.4				0.7					1.1
SS 1989/90	12.3										12.3
SS 1990/91						2.6					2.6
SS 1991/92	0.4										0.4
SS 1992/93									1.7		1.7
SS 1993/94*				93.5	1.0	3.8	0.2	0.2	8.5	0.1	107.3
SS 1994/95*				27.3					0.9		28.2
SS 1995/96*				4.0							4.0
HL 1995/96				4.3							4.3
Closed 1996/97	-	-	-	-	-	-	-	-	-	-	-
Closed 1997/98	-	-	-	-	-	-	-	-	-	-	-
HL 1998/99	-	-	-	0.2	-	-	-	-	-	-	0.2
HL 1999/00	-	-	-	0.3	-	-	-	-	-	-	0.3
HL 2000/01	-	-	-		-	-	-	-	-	-	
Total of 1988/89 to 2000/01	12.7	0.4	0	125.6	1.0	7.1	0.2	0.2	11.1	0.1	158.4
% of Total	8.0	0.3	0.0	79.3	0.6	4.5	0.1	0.1	7.0	0.1	

Table 4a. Summary of green sea urchin landings (tonnes) by South Coast management area and month in 1998/99, 1999/2000, and 2000/01 as reported on harvest logs. Only areas open to fishing, and months with catch, are reported. ("-" = closed to fishing).

	South Coast Management Areas								
Month	**11**	**12**	**13**	**17**	**18**	**19**	**20**	**28**	**Total (tonnes)**
1998 Nov.	0.0	10.4	3.8	0.0	1.0	0.7	0.0	0.0	15.9
Dec.	0.0	49.3	36.0	0.0	4.5	5.8	1.0	0.0	96.6
1999 Jan.	0.7	16.8	-	0.3	8.9	10.1	4.6	0.0	41.4
Feb.	0.0	-.	-	0.0	0.6	-	1.1	0.0	1.7
Area Totals	0.7	76.5	39.8	0.3	15.0	16.6	6.7	0.0	155.6
1999 Nov.	0.0	9.2	7.0	-	2.3	0.2	0.0	-	18.7
Dec.	0.0	57.5	47.7	-	6.2	8.8	3.7	-	123.9
2000 Jan.	2.6	38.7	1.6	-	0.3	-	-	-	43.2
Feb.	0.4	-	-	-	0.0	-	-	-	0.4
Area Totals	3.0	105.4	56.3	-	8.8	9.0	3.7	-	186.2
2000 Nov.	0.0	0.9	2.8	-	0.0	0.0	0.0	-	3.7
Dec.	0.0	29.2	50.1	-	9.2	9.1	0.0	-	97.6
2001 Jan.	0.0	71.7	3.3	-	0.0	0.0	2.3	-	77.3
Feb.	0.0	2.6	0.0	-	0.0	0.0	0.0	-	2.6
Area Totals	0.0	104.4	56.2	-	9.2	9.1	2.3	-	181.2

Table 4b. Summary of green sea urchin landings (tonnes) by North Coast management area and month in 1998/99, 1999/2000, and 2000/01 as reported on harvest logs. Only areas open to fishing, and months with catch, are reported. ("-" = closed to fishing).

	North Coast Management Areas	Total
Month	**4**	**(tonnes)**
1999 Feb.	0.0	0.0
Mar.	0.2	0.2
Area Total	0.2	0.2
1999 Nov.	0.0	0.0
Dec.	0.0	0.0
2000 Jan.	0.3	0.3
Feb.	0.0	0.0
Area Totals	0.3	0.3
2000 Nov.	0.0	0.0
Dec.	0.0	0.0
2001 Jan.	0.0	0.0
Feb.	0.0	0.0
Area Totals	0.0	0.0

Table 5. Green sea urchin landings reported on sales slips compared to harvest logbook or validation records, by fishing season (Oct./Nov. to Mar.), 1986/1987 to 2000/2001.

Season	Sales Slips (t)	Sales Slips (lb)	Harvest Logbooks (lb)	Validation Logbooks (lb)	% that Logbooks represent of Saleslip data
1986/87	n/a	n/a	5,220		n/a
1987/88	n/a	n/a	456,952		n/a
1988/89	480	1,055,758	832,625		79.4%
1989/90	642	1,416,184	1,067,996		75.4%
1990/91	455	1,003,315	778,926		77.6%
1991/92	783	1,726,341	1,660,117		96.2%
1992/93	978	2,156,128	2,103,210		97.5%
1993/94	577	1,271,440	1,174,527		92.6%
1994/95	223	490,886	487,590		98.8%
1995/96*	135	297,742	346,874	346,201	116.5%
1996/97*	133	294,186	330,526	330,504	112.4%
1997/98*	148	326,828	352,560	352,547	111.8%
1998/99*	107	236,943	343,579	344,161	145.0%
1999/00*	141	310,957	411,398	411,414	132.3%
2000/01*	86	190,632	399,665	399,671	209.7%

* Preliminary Data

Note: The above data assumes that all sales slips have been submitted annually, which may not always be the case. Sales slips landings for 1987 and 1988 are actually logs combined with a best guess from sales slips, as there was not a separate species code assigned to green sea urchins until the fall fishery in 1988.

Licence limitation was announced in 1989 for the 1991 fishery. Licence eligibility was based on landings from two of the three years 1987, 1998, and 1989. Fishers who knew they would not meet the landing criteria to get a limited licence were not inclined to submit harvest logbooks at the end of 1989 or in 1990, as they knew they could not renew their licence.

Table 6. Dynamic production model estimates for the parameters α, β, γ and their standard errors (in brackets) for the regression of equation 4. Regression coefficients (r^2), probability levels (p-values), and calculation from these parameters of the values of r, q, and k are as described in the text. Limit reference points MSY (maximum sustainable yield) and effort at MSY are calculated as described in the text.

	Regression Parameters				Management Parameters				
	α	β	γ	Model (r^2)	r $(yr)^{-1}$	q $(diver\ hr)^{-1}$	k (t)	MSY (t)	effort at MSY (diver hr)
South -inside Northern region (PFMA 11,12,13)	0.829 (0.192)	-0.0001 (0.00002)	-0.0071 (0.0018)	0.71	0.819	0.0001	1408	288	4967
p-level	0.002	0.014	0.003	0.002					
South - inside Southern region (PFMA 17-20,28)	0.373 (0.267)	-0.0002 (0.0001)	-0.0018 (0.0033)	0.34	0.373	0.0002	908	85	831
p-level	0.19	0.05	0.59	0.13					

Table 7. Results and biomass estimates from fishery-independent surveys conducted in the Gulf Islands region.

LOCATION	PFMA	DATE	MEAN DENSITY (#/m^2)		MEAN BIOMASS (g/m^2)		AREA (m^2)	TOTAL BIOMASS (t)	
			Sublegal	Legal	Sublegal	Legal		Sublegal	Legal
Collinson Point	18-02	Nov. 1999	21.23	0.46	470.75	38.56	458,717	215.9	17.7
(Active Pass)	18-02	Oct. 2000	26.05	1.80	580.73	99.38		266.4	45.6
Helen Point	18-02	Nov. 1997	0.04	0.04	1.63	5.08	197,778	0.3	1.0
(Active Pass)	18-02	Nov. 1999	2.03	0.93	44.54	62.55		8.8	12.4
Enterprise Reef (Active Pass)	18-02	Nov. 1997	0.08	0.22	2.08	39.83	182,425	0.4	7.3
East Point	18-11	Nov. 1999	21.30	2.13	362.93	130.38	993,734	360.7	129.6
(Saturna Island)	18-11	Oct. 2000	27.50	1.31	501.52	76.64		498.4	76.2
Arachne Reef	18-04/06 & 19-05	Mar. 2000	2.39	0.51	51.12	33.94	71,041	3.6	2.4
Cooper Reef	19-05	Mar. 2000	0.79	0.21	13.12	15.30	332,298	4.4	5.1
Sooke Bluffs	20-05/06	Jan. 2000	0.10	0.19	3.47	15.81	1,411,799	4.9	22.3
	20-05/06	Jan. 2001	0.00	0.00	0.00	0.00		0.0	0.0

Table 8. Calculations of limit and target reference points for green sea urchins in South Coast management areas, derived from the time series fitting surplus production method.. The ranges of quota options recommended for the 2001-2002 and 2002-2003 fishing seasons are in boldface. The MSY for PFMA 11-13 is 308, with a stock size at MSY of 905 t, assuming that this can be estimated by *k*/2. The MSY for PFMA 17-20,28 is 77 t, with a stock size at MSY of 375 t, assuming this can be estimated by *k*/2.

	Pacific Fishery Management Area – South Coast – inside waters												
	11	12	13	14	15	16	17	18	19	20	28	29	Total
Proportion caught (1988-2000) of the total for each Region	.016	.642	.342				.05	.405	.363	.157	.025		
MSY (t)	4.9	197.8	105.3				3.8	31.2	28.0	12.1	1.9		385.0
Exploitation Rate at MSY based on stock size at MSY (%)		34.0							20.5				
Precautionary reduction 0.5 * MSY (t)	**2.4**	**98.9**	**52.7**				**1.9**	**15.6**	**14.0**	**6.0**	**1.0**		**192.5**
Precautionary reduction 0.35*MSY (t)	**1.7**	**69.2**	**36.9**				**1.3**	**11.0**	**9.8**	**4.2**	**0.7**		**134.8**
Precautionary reduction 0.25*MSY (t)	**1.2**	**49.4**	**26.4**				**1.0**	**7.8**	**7.0**	**3.0**	**0.5**		**96.3**

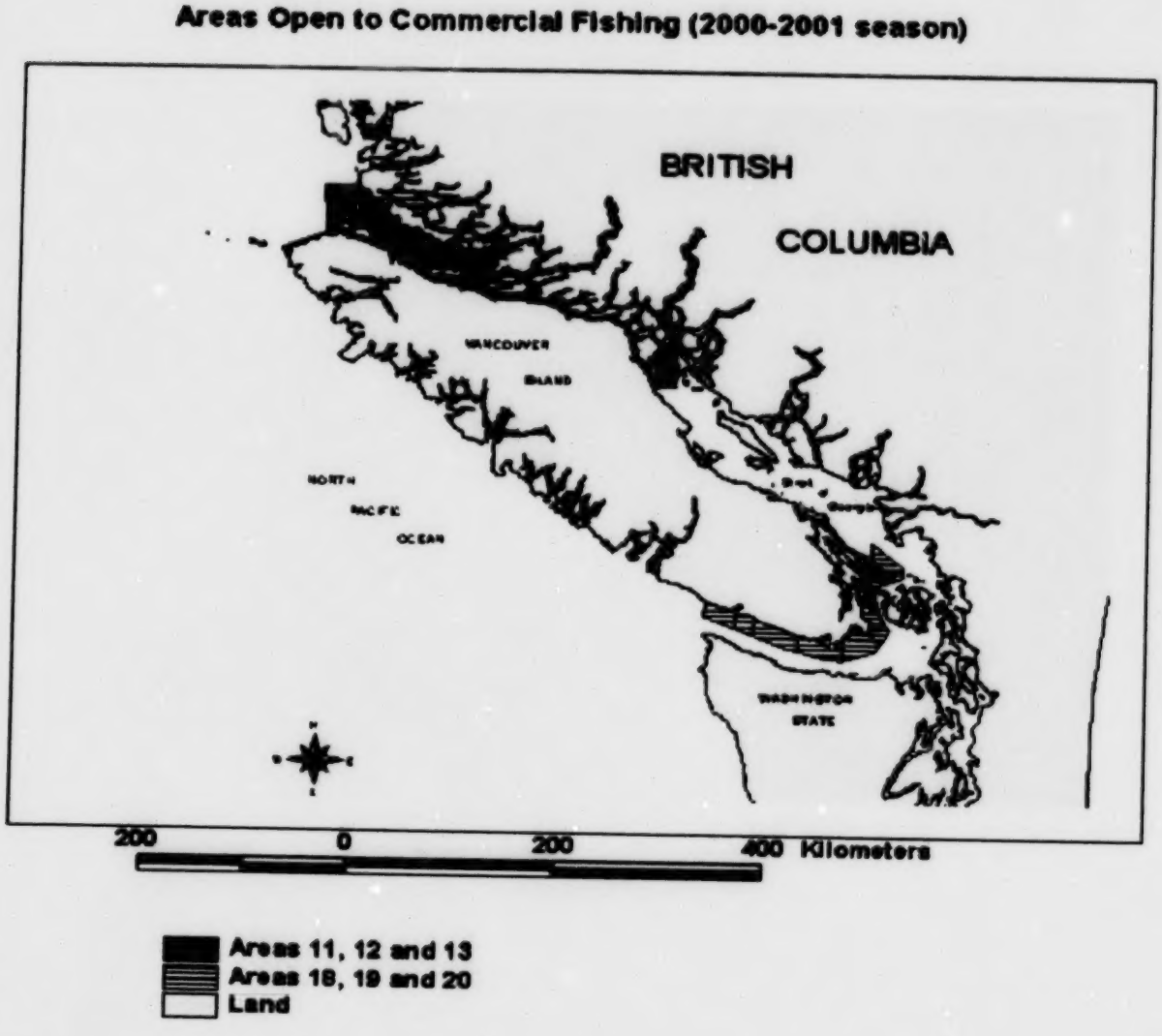

Fig. 1. Pacific Fishery Management Areas have been open to fishing for green sea urchins since 1995.

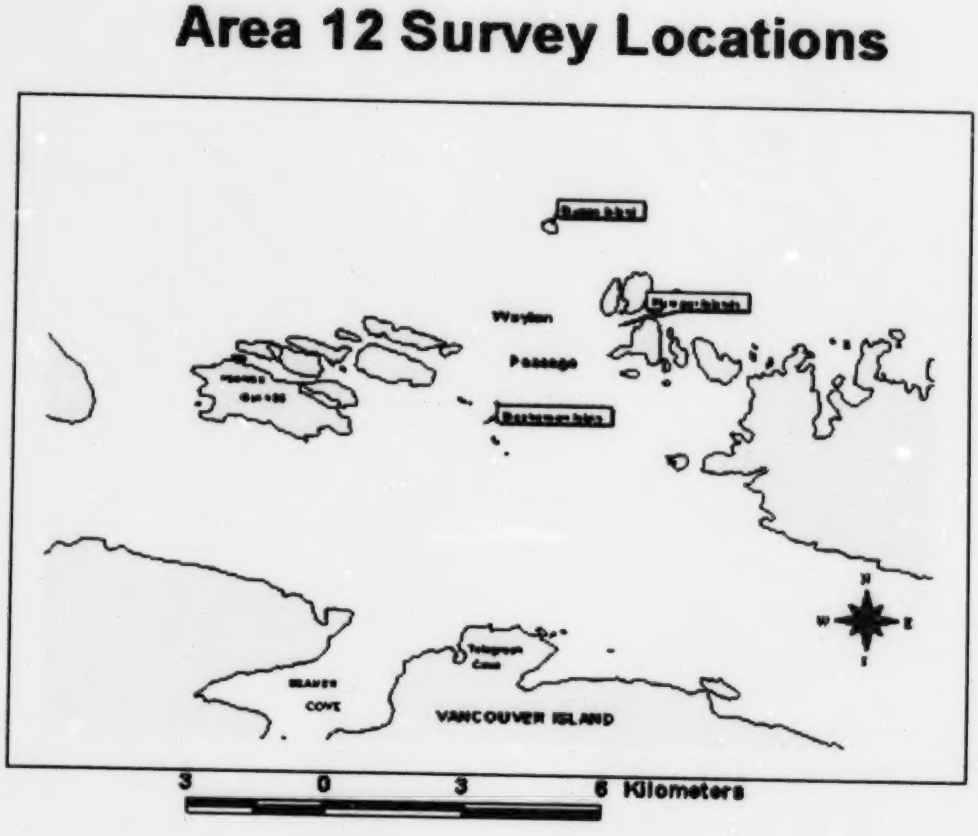

Fig. 2. Stephenson Islets location of the fishery-independent surveys conducted at the beginning of each fishing season from October 1995 to November 2000, eastern Queen Charlotte Strait, B.C.

Southern Vancouver Island Survey Locations

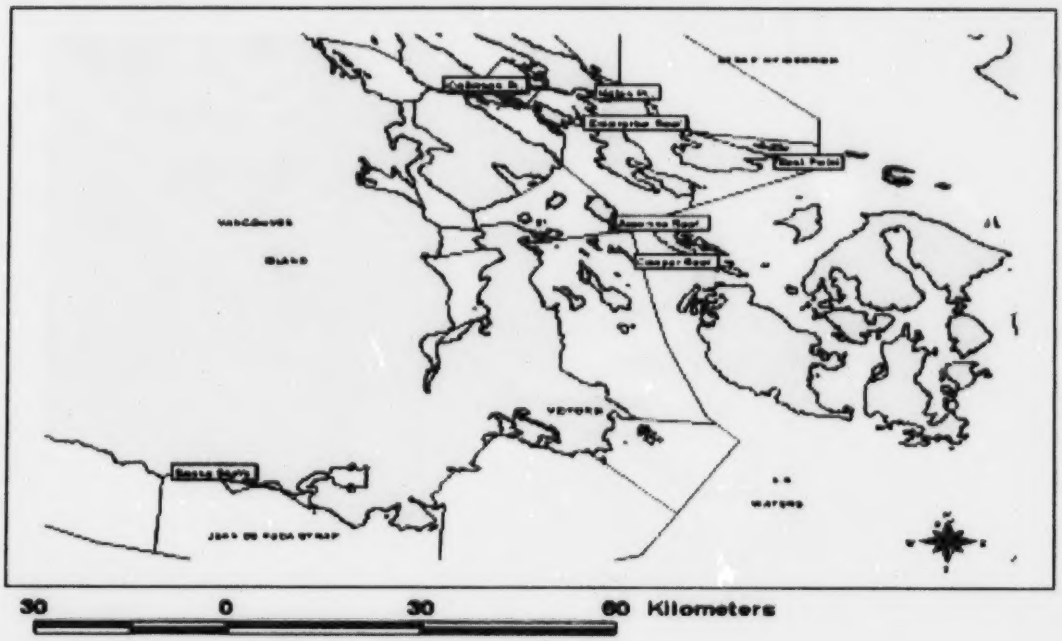

Fig. 3. Survey locations in the Gulf Islands region, 1997 to 2001.

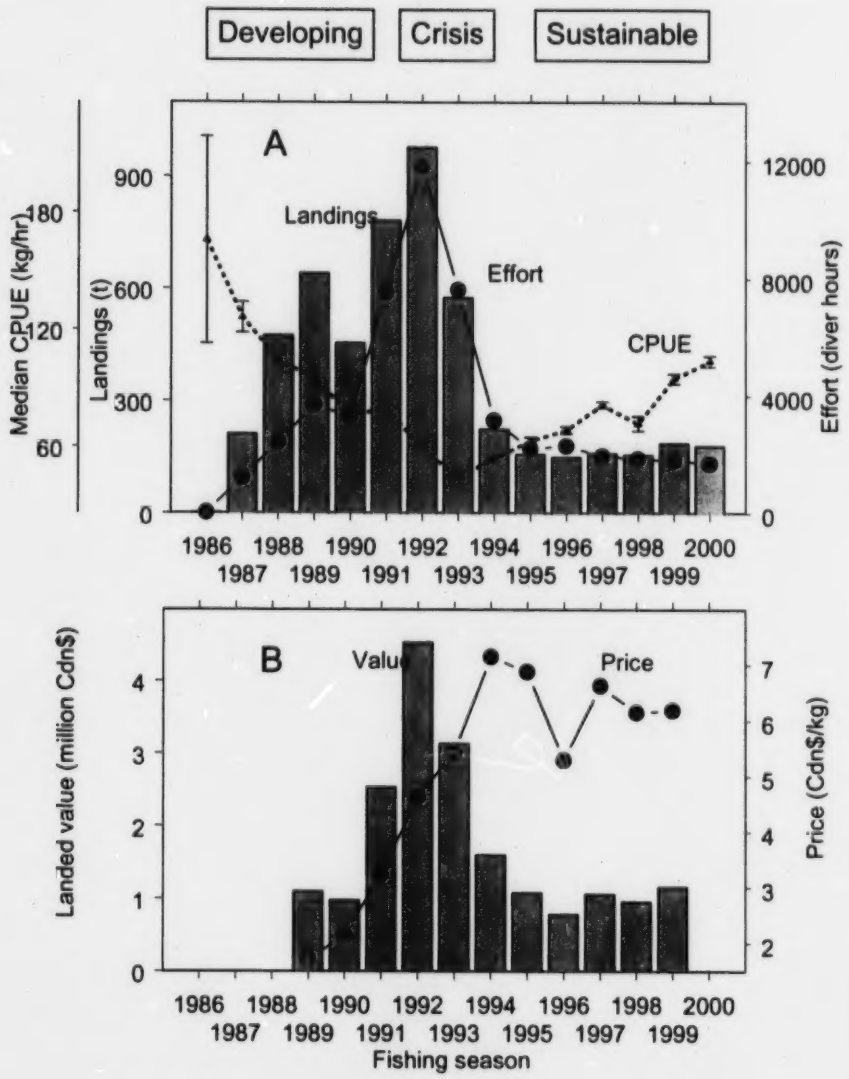

Fig. 4. (A) Landings (from sales slip data up to 1995, then from harvest and validation logs), effort, and CPUE; and (B) landed value for the green sea urchin fishery in B.C. and unit price – note data for 2000 are unavailable. Data are presented on the basis of a fishing season (October of year *i* to March of year *i*+1).

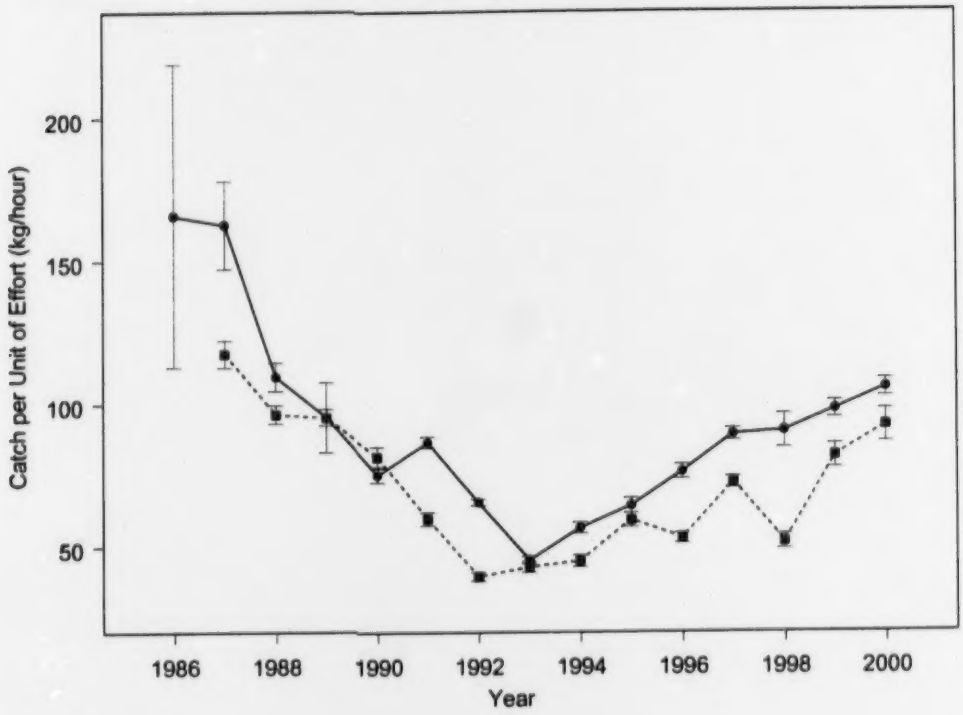

Fig. 5. Median catch per unit of effort ± 1 standard error (kg/diver hour) on a fishing season basis for the green urchin fishery in B.C.. Solid line: South Coast - inside waters northern component (PFMA 11, 12, 13); dashed line: South Coast - inside waters southern component (PFMA 17-20,28).

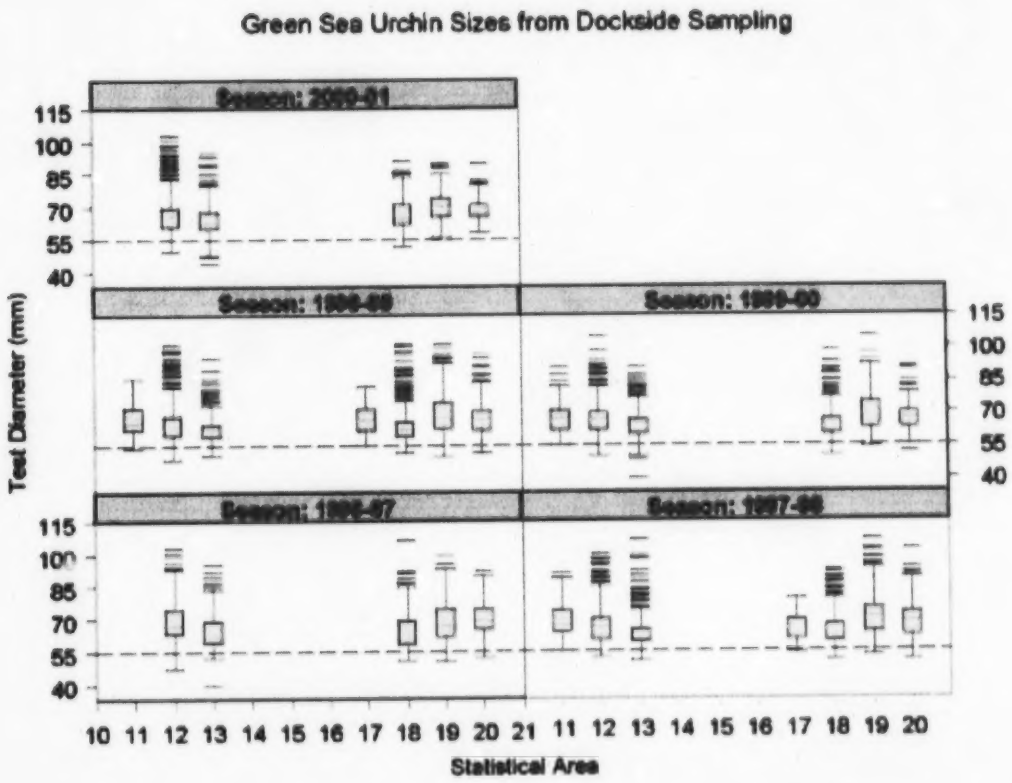

Fig. 6. Box and whisker plots of test diameters of green urchins sampled by port validators from each statistical area in each fishing season. White bar within box is the median, the upper and lower box edges define the 75th and 25th percentiles (interquartile distance), the whiskers represent values that fall within 1.5 times the interquartile distance, and separate lines represent outliers. Horizontal dashed line represents the legal size limit of 55 mm.

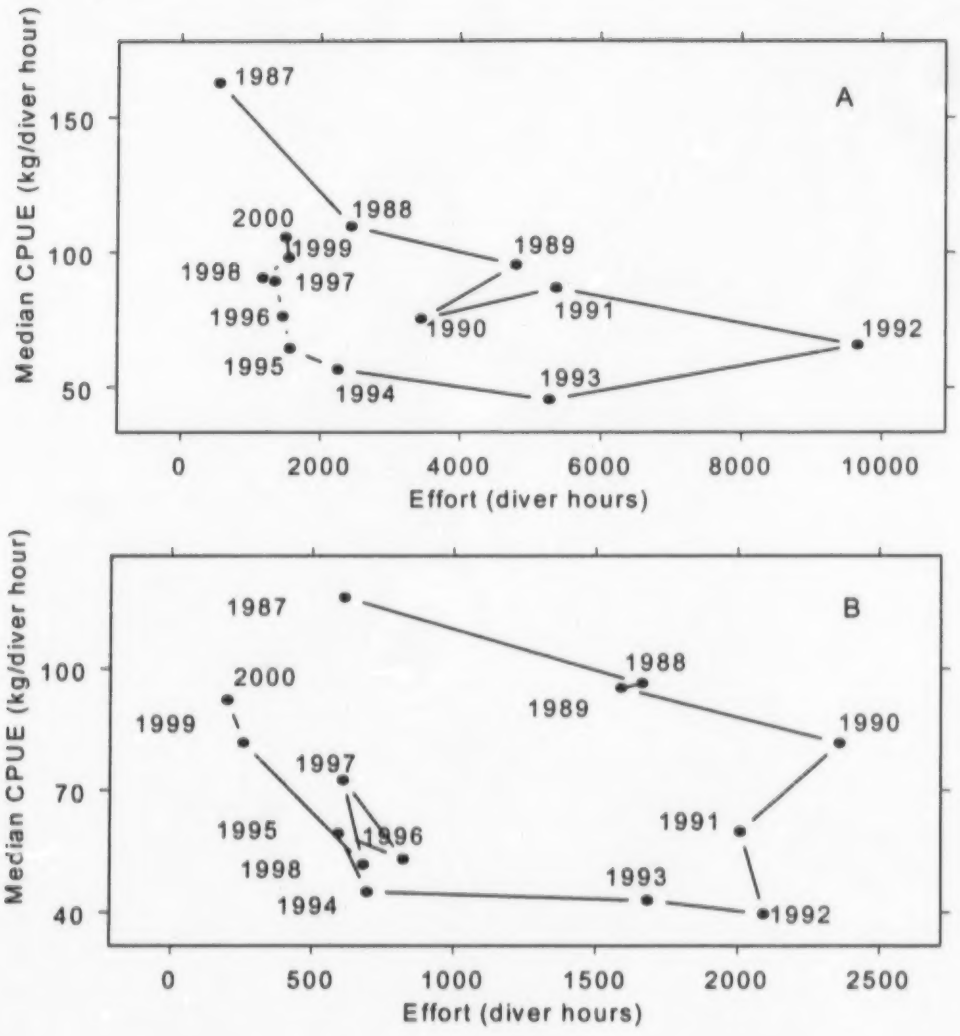

Fig. 7. Trajectories of median catch per unit of effort *versus* effort for the South Coast - northern (A) and southern (B) regions. Fishing seasons are indicated.

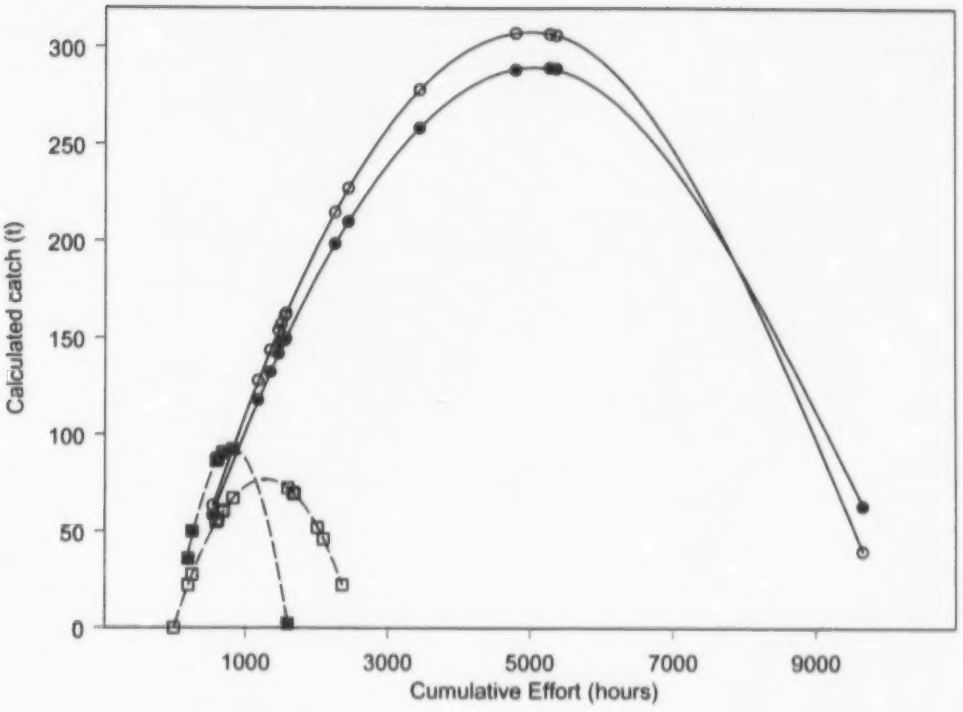

Fig. 8. Predicted Schaeffer model (text equation 5) for the biomass dynamic production model for the South Coast - inside waters northern region (PFMA 11-13; open and solid circles) and southern region (PFMA 17-20, 28; open and solid squares). Peak of the dome for each model represents the estimated MSY and effort at MSY. Solid symbols: predictions from the Schnute method; open symbols: predictions from the time series fitting method.

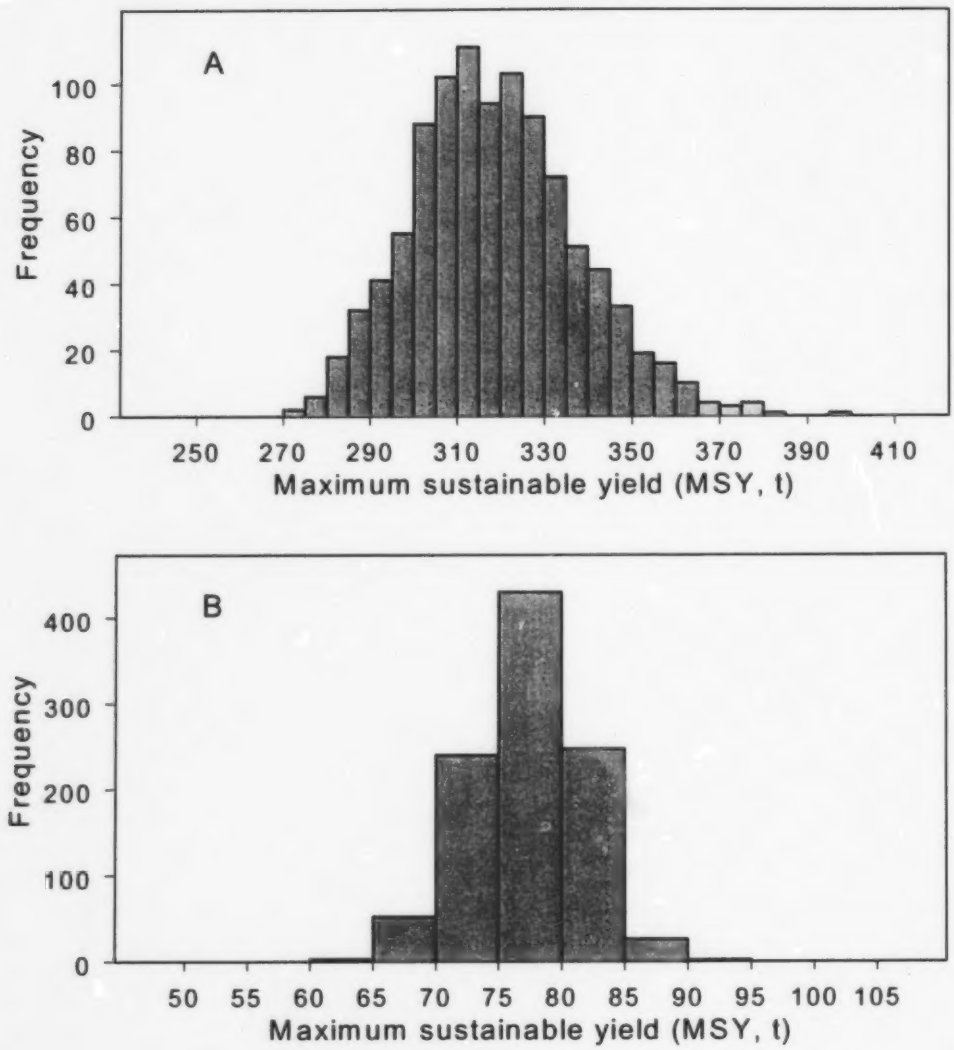

Fig. 9. Probability distribution for maximum sustainable yield (MSY) as estimated from the time series fitting method for the biomass dynamic model for: (A) Queen Charlotte Strait region (PFMA 11-13); and (B) Gulf Islands region (PFMA 17-20,28). Probability distributions are based on 1000 randomisations.

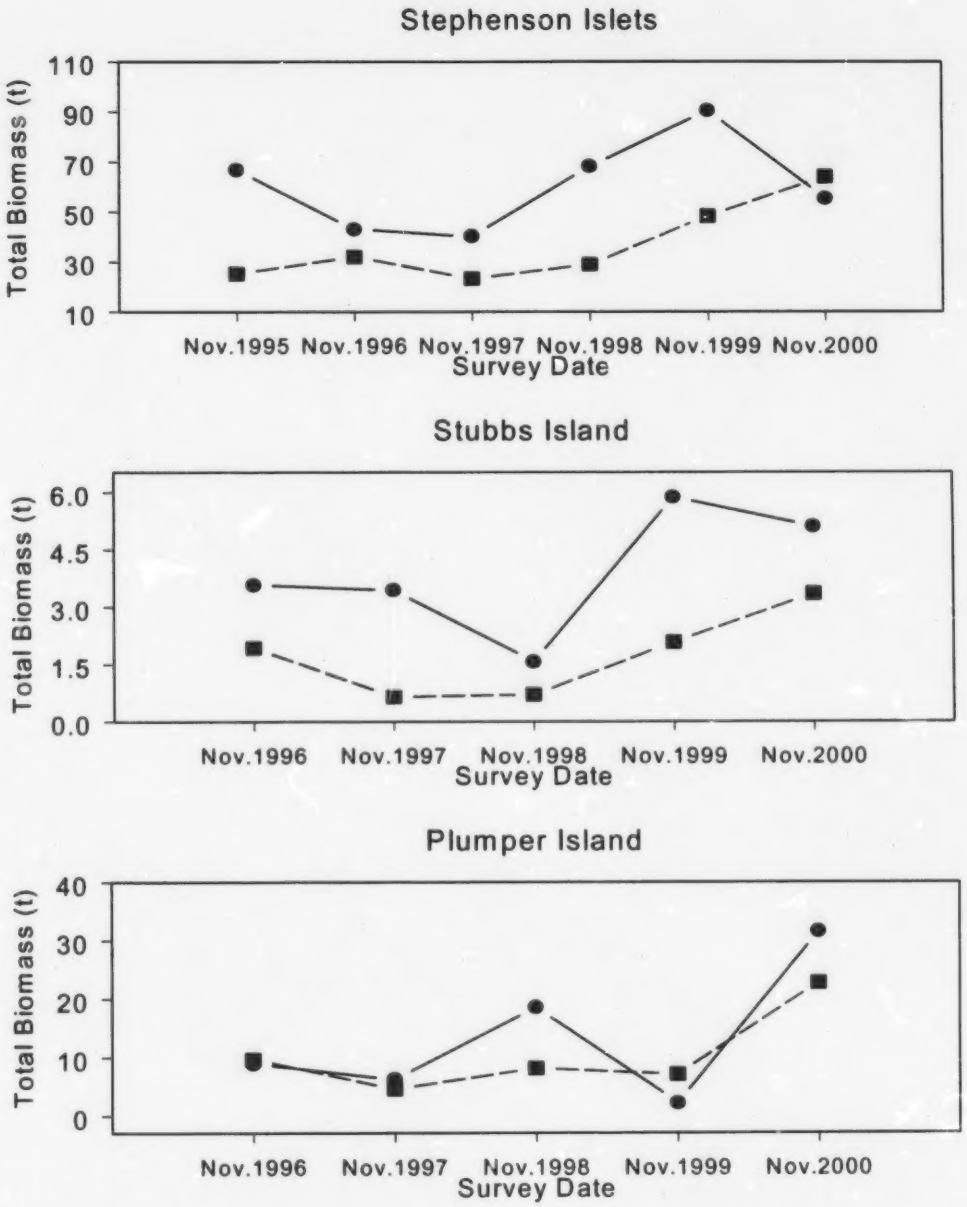

Fig. 10. Biomass estimates from fishery-independent surveys conducted annually in Area 12. Solid line: legal-sized biomass; dashed line: sub-legal sized biomass.

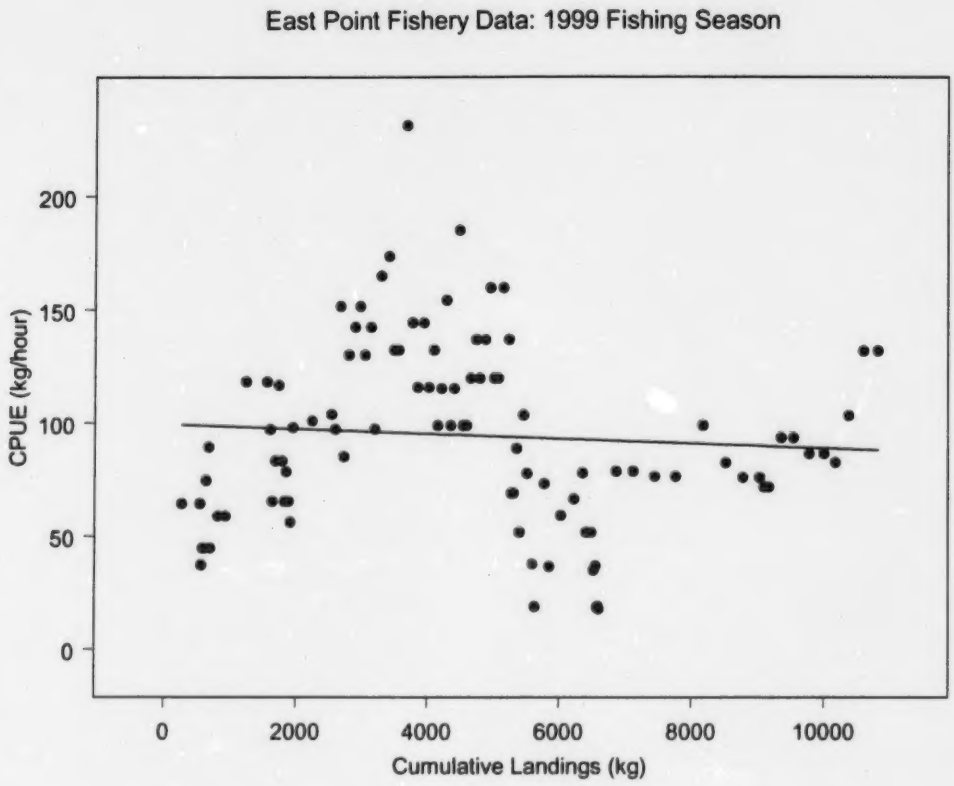

Fig. 11. Leslie depletion analysis of fishery-dependent data from East Point in Area 18 (Gulf Islands) during the 1999-2000 fishing season. The point at which the line intersects the X-axis is an estimate of the pre-fishing biomass at this location in November 1999.

APPENDIX 1. PSARC INVERTEBRATE SUBCOMMITTEE

Request for Working Paper

Date Submitted: June 26 2000

Individual or group requesting advice: Erin Wylie - Fish Management
(Fisheries Manager/Biologist, Science, SWG, PSARC, Industry, Other stakeholder etc.)

Proposed PSARC Presentation Date: January 1999

Subject of Paper (title if developed): Quota recommendations for Green Sea Urchin Fishery

Stock Assessment Lead Author: Ian Perry

Fisheries Management Author/Reviewer: Erin Wylie / Fiona Scurrah

Rational for request: Development of harvest/quota recommendations for the green sea urchin fishing plan (to begin late 2001)

Question(s) to be addressed in the Working Paper: Calculation of green sea urchin harvest quotas in all areas for which data is available. Incorporation of relevant information from recent green urchin surveys. Presentation of biological data collected from commercial fishery sampling (D&D).

Objective of Working Paper: analysis of harvest and validation log information and fishery independent survey data to provide harvest quota recommendations in the green sea urchin fishery.